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(54) Smooth upshift control method/system.

(57) A robust control method/system for smoo-
thing upshifts in an automated mechanical
transmission system (12) is provided. During the
torque recovery portion of an upshift, engine
deceleration (dES/dt) and the difference be-
tween current engine speed (ES) and a target
engine speed (ES_SYNC) and actuator response
times are utilized to sequence the issuance of
command output signals to the friction clutch
(24) and throttle override (34) actuators.

FIG. 2

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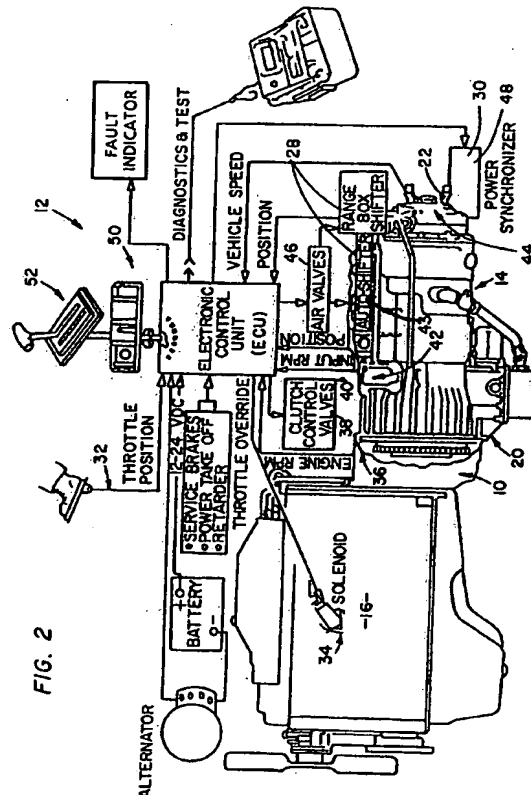
BACKGROUND OF THE INVENTION

Related Applications

This application is related to co-pending U.S. patent applications:

S.N. 698,751 entitled COMPOUND POWER DOWNSHIFT METHOD/SYSTEM;

S.N. 698,745 entitled RANGE SHIFTING ONLY FAULT TOLERANCE METHOD/SYSTEM;

S.N. 697,813 entitled THROTTLE CONTROL FAULT DETECTION AND TOLERANCE METHOD/SYSTEM;

S.N. 697,384 entitled TOOTH BUTT/BUZZ CONTROL METHOD SYSTEM;

S.N. 698,017 entitled DRIVELINE TORQUE LIMIT CONTROL STRATEGY-USING SAE JI922 TYPE ENGINE CONTROL;

S.N. 697,814 entitled TORQUE CONVERTER SLIP RATE BASED POWER DOWNSKIP SHIFT CONTROL STRATEGY;

all filed the same day, May 9 , 1991, and assigned to the same assignee, Eaton Corporation, as this application.

Field of the invention

The present invention relates to a control system and control method for controlling the operation of an automated mechanical transmission system, preferably of the type including an engine, a torque converter, a lock-up/disconnect clutch assembly and a mechanical transmission.

In particular, the present invention relates to a control system/method for an automated transmission system as described above wherein, during the torque recovery portion of an upshift transient, the reaction times of the involved actuators and of the engine are utilized to provide a timing and a sequence of actuation wherein the incipient reengagement of the clutch will occur when engine speed is substantially equal to transmission input shaft speed.

Description of the Prior Art

Mechanical transmission systems of the compound range, splitter or combined range and splitter type are well known in the prior art as may be seen by reference to U.S. Patent Nos. 4,788,889; 4,754,665 and 4,735,109, the disclosures of which are incorporated by reference.

Automatic mechanical transmission systems comprising mechanical transmissions and controls and actuators to automatically shift same, usually electronically controlled in accordance with sensed inputs and predetermined logic rules, are known. Examples of such systems may be seen by reference to U.S. patent Nos. 4,648,290; 4,595,986; 4,527,447; 4,361,060; 4,140,031 and 4,081,065, the disclosures of which hereby incorporated by reference. Such systems may also be seen by reference to SAE paper No. 831776 titled "AUTOMATED MECHANICAL TRANSMISSION CONTROLS", the disclosure of which is hereby incorporated by reference.

Fault tolerance logic routines for automatic transmissions are known as may be seen by reference to U.S. Patents Nos. 4,922,425, 4,849,899 and 4,899,279, the disclosures of which are hereby incorporated by reference.

Automatic transmission systems including a torque converter drivingly interposed a drive engine and a mechanical change gear transmission and/or including torque converter bypass or lock-up devices are also known as may be seen by reference to U.S. Patent Nos. 3,593,596; 4,261,216; 4,271,724; 4,351,205 and 4,375,171, the disclosures of which are hereby incorporated by reference.

Automatic mechanical transmission systems utilizing power synchronizer devices, i.e. devices independent of engine speed to provide input shaft braking and acceleration, and not manipulation of engine speed, to synchronize the transmission jaw clutch members are known in the prior art. Examples of such systems may be seen by reference to U.S. Patent Nos. 3,478,851, 4,023,443; 4,140,031 and 4,614,126, the disclosures of which are hereby incorporated by reference.

Automatic mechanical transmission systems having a power synchronizer and also having a torque converter drivingly interposed a drive engine and the transmission input shaft, and including a torque converter lock-up/disconnect clutch assembly, are known. Examples of such systems may be seen by reference to U.S. Patent Nos. 4,784,019 and 4,860,861 and S.A.E. Paper No. 881830 entitled "THE EATON CEEMAT (CONVERTER ENHANCED ELECTRONICALLY MANAGED AUTOMATIC TRANSMISSION)", the disclosures of which are hereby incorporated by reference.

Such transmission systems provide an automatic mechanical transmission system utilizing a mechanical change gear transmission of a structure identical or substantially identical to the structure of transmissions intended for manual usage, providing the advantages of a torque converter for vehicle start-ups and the advantages of nonslipping connection between the engine and transmission at higher vehicle speeds/gear ratios and providing relatively rapid synchronization of the transmission positive jaw clutches. By providing an automatic mechanical transmission system based upon the same, or substantially the same, mechanical change gear transmission utilized for manual transmission systems, manufacturing, inventory and maintenance cost savings are obtained. To the transmission is added, if necessary, shifting mechanisms suitable for automatic control by sole-

noids or the like. An example of such a shifting mechanism may be seen by reference to above-mentioned U.S. Patent Nos. 4,361,060 and 4,899,607 and U.S. Patent Nos. 4,873,881; 4,722,237 and 4,445,393, the disclosures of which are hereby incorporated by reference. A power synchronizer mechanism as disclosed in above-mentioned U.S. Patent Nos. 4,614,126; 3,478,851 or 4,023,443 is also added for synchronizing the transmission positive jaw clutches.

A torque converter is drivingly interposed the drive engine and transmission. A torque converter lock-up and disconnect clutch structure is provided comprising a first and a second separate, independently operable, clutches, preferably friction clutches, for coupling the torque converter driven member or turbine to the transmission input shaft and for coupling the torque converter input or impeller (i.e. the engine output) to the transmission input shaft, respectively.

The torque converter is drivingly interconnected between the engine and transmission only when the first coupling is engaged and the second disengaged. The torque converter is locked-up, i.e. the turbine driven directly by the engine, when the second clutch is engaged. The transmission is driven directly from the engine, whenever the second clutch is engaged simultaneously with the first clutch.

When the first coupling is disengaged, regardless of the condition of the second coupling, the transmission input shaft is disconnected from the engine torque and also from the inertia of the torque converter and from the inertia of the second coupling allowing the jaw clutches to be easily disengaged, the power synchronizer mechanism to act quickly due to relatively low inertia on the input shaft and also allowing a selected gear to be pre-engaged with the vehicle at rest and in the drive condition.

With automated transmission systems of the type described, i.e., an automatic transmission that is derived from a manual transmission, shift quality, especially during torque recovery, is very critical to the customers and/or operators impression of the product. The transmission system must successfully operate with a variety of engines and vehicle applications. The engine response to the shift control sequence has a most significant affect on shift quality and every engine responds differently. Having specialized control logic for each engine and vehicle application is very understandable. The control method/system needs a means of adapting to the response characteristics of an engine during a shift that will provide good shift quality and reduce the requirement of specialized control logic for different engines.

SUMMARY OF THE INVENTION

In accordance with the present invention, the drawbacks of the prior art are overcome or minimized by the provision, in an automated mechanical transmission system of the type described, of torque recovery logic routines which provide for smooth reengagement, and thus good shift quality, of the transmission system during an upshift while not requiring specialized logic for each engine and vehicle combination.

The above is accomplished, preferably in an automatic mechanical transmission system based upon a mechanical change gear transmission to which is added shifting mechanisms suitable for automatic control, a power synchronizer mechanism as disclosed in above-mentioned U.S. Patent Nos. 4,614,126, a torque converter drivingly interposed the drive engine and transmission and a torque converter lock-up and disconnect clutch structure comprising a first and a second separate, independently operable, clutches, preferably friction clutches, for coupling the torque converter driven member or turbine to the transmission input shaft and for coupling the torque converter input or impeller (i.e. the engine output) to the transmission input shaft, respectively, by the provision of torque recovery logic routines which use sensed or predetermined clutch and fuel controller actuator response times and which monitors current engine deceleration rates, to determine a timing and sequence of relative actuation of various system actuators to achieve a smooth, high quality reengagement of the transmission system.

Accordingly, it is an object of the present invention to provide a new and improved automatic mechanical transmission system utilizing power synchronizer, a torque converter drivingly interposed the engine and mechanical transmission and further utilizing an improved torque converter lock-up and disconnect clutch structure.

Another object of the present invention is to provide, in an automated mechanical transmission system, robust torque recovery logic routines to achieve relatively smooth reengagement of the transmission system during an upshift operation.

These and other objects and advantages of the present invention will become apparent from a reading of the description of the preferred embodiment taken with the drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a schematic view of the torque converter and torque converter disconnect and bypass clutch structure of the present invention.

Figure 2 is a schematic illustration of the automatic mechanical transmission system of the present invention.

Figure 3 is a partial view, in section, of the automatic mechanical transmission system of the present invention.

Figure 4 is a graphical representation of a typical shift sequence for the transmission of Figure 2.

Figure 5 is a symbolic representation of the shift

pattern for the transmission of Figure 3.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Certain terminology will be used in the following description for convenience and reference only and will not be limiting. The words "upwardly", "downwardly", "rightwardly" and "leftwardly" will designate directions in the drawings to which reference is made. The words "inwardly", and "outwardly", refer to directions towards and away from, respectively, the geometric center of the device and designated parts thereof. The above applies to the words above specifically mentioned, derivatives thereof and words of similar import.

As used herein, a "higher gear ratio" will refer to a drive ratio having a lower ratio of input shaft speed to output shaft speed. For example, third (3rd) speed is higher than second (2nd) speed and a shift from second to third speed is an "upshift".

The torque converter lock-up and disconnect clutch assembly 10 and an automatic mechanical transmission system 12 utilizing same, of the present invention, are schematically illustrated in Figures 1, 2 and 3. The term "automatic mechanical transmission system" as used herein, shall mean a system comprising at least a throttle device controlled heat engine 16, a multi-speed jaw clutch type change gear transmission 14, a nonpositive coupling device such as a master friction clutch and/or a fluid coupling 10/20 interposed the engine and the transmission and a control unit 50 for automatically controlling same. Such systems will, of course, also include sensors and/or actuators for sending input signals to and/or receiving command output signals from the control unit.

While the present invention is particularly well suited for use in connection with transmission systems having a torque converter and torque converter lock-up/disconnect clutch, the invention is also applicable to transmission systems having a standard friction master clutch drivingly interposed the engine and the transmission.

The automatic mechanical transmission system 12 of the present invention is intended for use on a land vehicle, such as a heavy duty truck, but is not limited to such use. The automatic mechanical transmission system 12 illustrated includes an automatic multi-speed mechanical change gear transmission 14 driven by a prime mover throttle device controlled engine 16 (such as a diesel engine) through a fluid coupling or torque converter assembly 20. The output of the automatic transmission 14 is an output shaft 22 which is adapted for driving connection to an appropriate vehicle component such as the differential of a drive axle, a transfer case, or the like as is well known in the prior art.

As will be discussed in greater detail below, the torque converter lock-up and disconnect clutch assembly 10 includes two separate, independently engageable clutches, preferably friction clutches, a torque converter disconnect clutch 24 and a torque converter lock-up or bypass clutch 26. The transmission 14 includes a transmission operating mechanism 28 which is preferably in the format of a pressurized fluid actuated shifting assembly of the type disclosed in above-mentioned U.S. Patent No. 4,445,393. The transmission also preferably includes a power synchronizer assembly 30 which may be of the type illustrated and disclosed in above-mentioned U.S. Patent Nos. 3,478,851, 4,023,443 or 4,614,126.

The above-mentioned power train components are acted upon and monitored by several devices, each of which are known in the prior art and will be discussed in greater detail below. These devices may include a throttle position monitor assembly 32, which senses the position of the operator controlled vehicle throttle pedal or other fuel throttling device, a throttle control 34 which controls the supply of fuel to the engine, an engine speed sensor assembly 36 which senses the rotational speed of the engine, a torque converter disconnect clutch and lock-up clutch operator 40 which operates the torque converter disconnect and lock-up clutches, a transmission input shaft speed sensor 42, a transmission output shaft speed sensor 44, a transmission shifting mechanism operator 46 for controlling the operation of transmission shifting mechanism 28 and/or a power synchronizer mechanism actuator 48 for controlling the operation of power synchronizer mechanism 30.

The throttle control 34 may simply be an override device to reduce ("dip") fuel to the engine to a set or variable level regardless of the operator's positioning of the throttle pedal. Alternatively, the control 34 may be an electronic fuel/engine control conforming to SAE JI922 or a similar standard.

The above-mentioned devices supply information to and/or accept commands from an electronic central processing unit (ECU) 50. The central processing unit or controller 50 is preferably based on a digital microprocessor, the specific configuration and structure of which form no part of the present invention. The central processing unit 50 also receives information from a shift control or mode selector assembly 52 by which the operator may select a reverse (R), a neutral (N) or several forward drive (D, D_L) modes of operation of the vehicle. Typically, the D mode of operation is for on-highway vehicle travel while the D_L mode of operation is for off-road operation.

Typically, the system also includes various sensors, circuits and/or logic routines for sensing and reacting to sensor and/or actuator failures.

As is known, the central processing unit 50 receives inputs from the various sensors and/or operating devices. In addition to these direct inputs, the central processing unit 50 may be provided with circuitry

and/or logic for differentiating the input signals to provide calculated signals indicative of the rate of change of the various monitored devices, means to compare the input signals and/or memory means for storing certain input information, such as the direction of the last shift, and means for clearing the memory upon occurrence of predetermined events. Specific circuitry for providing the above-mentioned functions is known in the prior art and an example thereof may be seen by reference to above-mentioned U.S. Patent Nos. 4,361,060 and 4,595,986 and/or by reference to a technical paper entitled "THE AUTOMATION OF MECHANICAL TRANSMISSIONS" published proceedings of a joint IEEE/SAE conference entitled International Congress 20 on Transportation Electronics, IEEE Catalog Number 84CH1988-5, the disclosure of which is hereby incorporated by reference.

Preferably, the system 12 will also include logic routines and sensors for sensing the "touch point" or incipient engagement of the clutch 24, or of a master friction clutch. See for example, U.S. Patents Nos. 4,899,838; 4,853,629 and 4,646,891, the disclosures of which are incorporated by reference.

As is well known in the operation/function of electronic control units, especially microprocessor based ECUs, the various logic functions can be performed by discrete hardwired logic units or by a single logic unit operating under different portions or subroutines of the control system logic rules (i.e. the software).

A more detailed schematic illustration of the torque converter 20 and torque converter lock-up and disconnect clutch assembly 10 drivingly interposed engine 16 and automatic change gear transmission 14 may be seen by reference to Figure 1. The torque converter assembly 20 is conventional in that it includes a fluid coupling of the torque converter type having an impeller 54 driven by the engine output or crank shaft 56 through a shroud 58, a turbine 60 hydraulically driven by the impeller and a stator or runner 62 which becomes grounded to a housing 64 via a one-way roller clutch 66 carried by a shaft 68 grounded to the housing 64. Shroud 58 also drives a pump 70 for pressurizing the torque converter, lubricating the transmission, selectively pressuring the transmission shifting mechanism 28 and/or power synchronizing mechanism 30 and/or operating the disconnect and bypass clutches 24 and 26. Pump 70 may be of any known structure such as, for example, a well known crescent gear pump.

The transmission 14 includes an input shaft 72 driven by the engine 16 via the torque converter assembly 20 and/or lock-up and disconnect clutch assembly 10. Transmission input shaft 72 carries a connecting member 74 fixed thereto for rotation therewith. Connecting member 74 includes a portion 76 associated with the torque converter disconnect clutch 24 and a second hub portion 78 splined for association with the input shaft. Briefly, as will be described

in greater detail below, torque converter disconnect clutch 24 may be engaged or disengaged, independently of engagement or disengagement of lock-up clutch 26, to frictionally engage or disengage a connecting member 79 which is associated with the torque converter turbine 60 and a member of the lock-up clutch 26, to and from the transmission input shaft 72 via portion 76 of connecting member 74. Torque converter lock-up clutch 26 may be frictionally engaged or disengaged, independent of the engagement or disengagement of disconnect clutch 24, to frictionally engage the engine crankshaft 56, and shroud 58 driven thereby, to the connecting member 79.

Engagement of torque converter lock-up clutch 26 will engage the engine crankshaft 56, via shroud 58, directly with the connecting member 79, regardless of the engaged or disengaged condition of torque converter disconnect clutch 24, and thus provides an effective lock-up for locking-up the torque converter 20 and driving transmission 14 directly from the engine 16 if disconnect clutch 24 is engaged. Additionally, at speeds above torque converter lock-up speed, the lock-up clutch 26 need not be engaged and disengaged during shifting as disengagement of clutch 24 disconnects the inertia of connection member 79 from input shaft 72.

If the torque converter bypass clutch or lock-up 26 is disconnected, and the torque converter disconnect clutch 24 is engaged, the transmission 14 will be driven from engine 16 via the torque converter fluid coupling as is well known in the prior art. If the torque converter disconnect clutch 24 is disengaged, regardless of the condition of lock-up clutch 26, the transmission input shaft 72 is drivingly disengaged from any drive torque supplied by the engine or any inertial drag supplied by the torque converter, the engine and clutch 26. Disconnecting of the transmission input shaft 72 from the inertial affects of the engine, clutch 26 and/or torque converter allows the rotational speed of the input shaft 72, and all transmission gearing drivingly connected thereto, to be accelerated or decelerated by the transmission power synchronizer mechanism 30 in a more rapid manner for purposes of more rapidly achieving synchronization during a downshift or upshift of the transmission and also allows the power synchronizer 30 to cause the input shaft 72 to rotate at a rotational speed greater than any governed engine speed.

When the vehicle is at rest with the mode selector in the drive or off-highway drive mode, the disconnect clutch 24 will be engaged and the lock-up clutch 26 disengaged allowing for torque converter start-up with its well known advantages. At above a given vehicle speed and/or gear ratio, the advantages of torque converter operation are no longer required, and the increased efficiency of a direct drive between the drive engine and transmission is required. Upon these conditions, the torque converter lock-up clutch 26 will be

maintained engaged allowing the transmission input shaft 72 to be driven directly from the engine via the torque converter shroud 58 and connecting member 79 when the disconnect clutch 24 is engaged.

As discussed above, clutch 24 will be disengaged to shift from a previously engaged gear to neutral, to allow the power synchronizer 30 to synchronize the jaw clutch members of the gear to be engaged and to allow engagement of the synchronized jaw clutches of the gear to be engaged.

Selection of the desired gear ratio and selection of the required engaged or disengaged condition of the torque converter disconnect or lock-up clutches, as well as the issuance of command signals to the various clutch and transmission operators is accomplished by the central processing unit 50 in a manner which is known in the prior art and which may be appreciated in greater detail by reference to above-mentioned U.S. Patent Nos. 4,361,060 and 4,595,986.

The compound transmission 14 is illustrated in in greater detail in Figure 3 and is of the type wherein the main section countershaft or countershafts 90 are coaxially aligned with the auxiliary section countershaft or countershafts 92. Transmission 14 is of a relatively standard design and is preferably of the twin countershaft type only one of which countershafts in the main and auxiliary sections, 94 and 96, respectively, is shown. Examples of such transmissions having coaxially aligned main section and auxiliary section countershafts may be seen by reference to U.S. Patent Nos. 3,105,395 and 3,138,965, the disclosures of which are incorporated by reference.

Transmission 14 includes input shaft 72 to which member 78 is fixed for rotation therewith and which additionally carries input gear 98 nonrotatably attached thereto. Main section countershaft 90 is substantially parallel to mainshaft 100 and is provided with countershaft gears 102, 104, 106, 108, 110 and 112 fixed for rotation therewith. A plurality of mainshaft gears, also called ratio gears, 114, 116, 118 and 120, surround the mainshaft and are selectively clutchable thereto, one at a time, by double sided positive jaw clutch collars 122, 124 and 126. Jaw clutch collar 122 may also clutch the input shaft 72 directly to the mainshaft 100 while clutch collar 126 may clutch reverse mainshaft gear 128 to the mainshaft.

The mainshaft gears 114, 116, 118 and 120 circle the mainshaft and are in continuous meshing engagement with, and are preferably supported by, opposed pairs of countershaft gears 104, 106, 108 and 110 which mounting means and the special advantages resulting therefrom are explained in greater detail in above-mentioned U.S. Patent Nos. 3,105,395 and 3,335,616. Reverse mainshaft gear 128 is in continuous meshing engagement with countershaft gear 112 by means of conventional intermediate idler gears (not shown). The forwardmost countershaft gear 102

is continuously meshed with and driven by input gear 98 for causing rotation of countershaft 90 whenever the input gear is rotatably driven.

Clutch collar 122 carries positive jaw clutch teeth 98b and 114b which are engageable with clutch teeth 98a and 114a, respectively, to define positive jaw clutches 98c and 114c, respectively. Clutch collar 124 carries positive jaw clutch teeth 116b and 118b which are engageable with jaw clutch teeth 116a and 118a, respectively, to define positive jaw clutches 116c and 118c, respectively. Jaw clutch collar 126 carries jaw clutch teeth 120b and 128b which are positively engageable with jaw clutch teeth 120a and 128a, respectively, to define positive jaw clutches 120c and 128c, respectively.

As is known in the prior art, each of the clutch collars are preferably directly or indirectly splined to the mainshaft for rotation therewith and axial movement relative thereto. Other mounting means for the clutch collars are known in the prior art and are intended to be included within the scope of the present invention. Each of the clutch collars 122, 124, and 126 is provided with means for receiving a shift fork or shift yoke 130, 132 and 134, respectively, whereby the clutch collars are axially moved, one at a time only, from the positions illustrated in Figure 3 by the actuator 28.

The auxiliary transmission section 96 includes output shaft 22 which is preferably coaxial with input shaft 72 and mainshaft 100 and is supported for rotation in a transmission housing by means of bearings. The auxiliary section also includes an auxiliary section countershaft 92 supported for rotation in the housing by means of bearings. Fixed for rotation with mainshaft 100 is the auxiliary section drive gear 136. Auxiliary section countershaft 92 carries auxiliary section countershaft gears 138 and 140 fixed for rotation therewith. Auxiliary section countershaft gear 138 is constantly meshed with auxiliary section input gear 136 while auxiliary section countershaft gear 140 is constantly meshed with output gear 142 which surrounds the output shaft 22. A synchronized clutch structure 144, of conventional individually synchronized jaw clutch design, is utilized to selectively clutch mainshaft 100 and auxiliary drive gear 136 directly to the output shaft 22 for a direct drive connection between the mainshaft and output shaft or to clutch output gear 142 to the output shaft 22 for a reduction drive of output shaft 22 from mainshaft 100 through countershaft 92 as is well known in the prior art. Synchronized clutch structure 144 is controlled by shift fork 146 axially moved by actuator 28.

Transmission 14 is of the range type wherein the auxiliary section ratio step (or steps) is greater than the total ratio coverage of the main section ratios appearing in all ranges. Such transmissions are well known in the prior art, see U.S. Patent No. 4,754,665, the disclosure of which is hereby incorporated by reference.

The power synchronizer assembly 30 includes a planetary speed increasing gear set driven by the output shaft 22 independently of the rotational speed of the drive engine 16, and selectively actuatable to accelerate the rotational speed of transmission elements driven by the input shaft 72 for purposes of synchronous rotation of jaw clutch members associated with the gear ratio to be engaged. preferably, the power synchronizer assembly 30 will also include means to decelerate the transmission elements driven by the input shaft. Deceleration of the transmission elements driven by the input shaft may also be achieved by input shaft and/or engine braking devices which will preferably be controlled by central processing unit 50.

Details of construction and operation of the power synchronizer assembly 30 may be appreciated in greater detail by reference to above-mentioned U.S. Patent No. 4,614,126. The present inventions also applicable to automated mechanical transmission systems wherein a power synchronizer is not utilized.

The shift sequence for a simple shift of transmission 14 in system 12 is illustrated in Figure 4. Assuming the ECU 50 determines that a shift from second (2nd) to third (3rd) speed is required (i.e. a simple upshift), the ECU will cause fuel controller 34 to defuel (i.e. "dip") the engine regardless of the position of the throttle pedal 32. While the engine is being defueled, the disconnect clutch (or master clutch) 24 is disengaged and shift to main section 94 neutral is undertaken.

Upon defueling the engine, declutching the disconnect clutch and disengaging the main section, the power synchronizer is actuated to cause the mainshaft gearing (in this example 3rd speed mainshaft gear 114) to rotate at a target or substantially synchronous speed relative to mainshaft 100 as determined by output shaft speed and auxiliary section 96 ratio. Output shaft speed is sensed by sensor 44 while the speed of the various mainshaft gears is a known multiple of input shaft 72 speed as sensed by sensor 42.

The rail select function can occur at any time after main section disengagement and main section reengagement in the new ratio is timed to occur as the power synchronizer is bringing the engaged gear towards target speed. Of course, for an upshift the power synchronizer is normally required to retard the speed of the input shaft and associated gearing.

Upon achieving engagement of the proper main section ratio, the disconnect clutch is reengaged and the engine refueled.

Typically, a simple shift can be accomplished in about 0.70 to 0.80 seconds with a disconnect (i.e. torque break) time of about 0.50 seconds.

System 12 is an automatic transmission system that is derived from a mechanical manual transmission. Shift quality is very critical to the users and/or customers impression of the transmission system and the system must successfully operate with a variety of engines and vehicle applications. The engine response to the shift control sequence has a most significant effect on shift quality and every engine responds differently. Having specialized control logic for each engine and vehicle application would be undesirable and a logistical nightmare.

The control for system 12 should be capable of adapting to the response characteristics of an engine during a shift that will reduce the requirement of specialized logic for different engines. Such control logic is usually referred to as "robust".

The shift sequence is broken up into three parts, torque interrupt, gear selection, and torque recovery. The torque interrupt portion of a shift is that which smoothly interrupts the powerflow of the engine to the driveline. The gear select portion sequences the shifting mechanisms to engage the desired gear ratios. The torque recovery sequence engages the torque converter clutches and restores engine power to complete the entire shift sequence. The most critical sequence with respect to shift quality is the torque recovery portion. Improper timing of clutch engagement and engine refuel during torque recovery can have significantly adverse effects on shift quality. The critical event for shift quality in the torque recovery portion of the shift sequence is reactivating the clutch and refueling the engine when the engine is nearly synchronized with the input shaft of the transmission.

To achieve a high quality upshift, during torque recovery, the ECU 50 should issue command outputs to the clutch and the throttle dip actuators in a timed sequence such that the disconnect clutch (or master clutch) should be moved from disengagement to incipient engagement at about the same instant that the speed of engine 16 (ES) is substantially equal to input shaft speed (IS). Input shaft speed may be sensed directly or may be estimated as a function of vehicle speed (sensed by output shaft speed (OS)) which is usually relatively constant during a shift transient, and engaged gear ratio (GR).

If the torque converter lock-up clutch 26 is not engaged, i.e., the torque converter is slipping, the target speed (ES_{SYNC}) may be adjusted accordingly.

The clutch and throttle-dip actuators (34, 38/40) response times, along with the rate of deceleration of the engine, play a major role in the critical timing of torque recovery. The actuator response times are relatively consistent from one system to another but the engine deceleration rate (dES/dt) varies from engine to engine and between cold mornings and hot afternoons, etc.

The basic premise of sequencing the actuators during the torque recovery portion for improved shift quality is to first predict when the engine will be synchronized with the input shaft speed and then to time sequence the actuators such that their effective response will revolve around engine synchronization.

Assuming an upshift, at the very beginning of the torque recovery portion of the shift sequence, a difference (ES_{DELTA}) between the current engine speed ($ES_{CURRENT}$) and the target engine speed for synchronization (ES_{SYNC}) is determined as a function of the expression:

$$ES_{DELTA} = ES_{CURRENT} - E_{SYNC}.$$

The rate of engine deceleration (dES/dt) is sensed/calculated and the time until engine speed equals the target speed (Engine_Sync_Time) is determined as a function of dividing the engine speed difference by the determined engine deceleration rate:

$$\text{Engine\_Sync\_Time} = ES_{DELTA}/(dES/dt^2).$$

Each actuator response time is then compared to the Engine_Sync_Time to determine when an actuating command signal should be issued by CPU 50 to that particular actuator.

The response time of the throttle dip actuator 34 is the time from command until the mechanism begins to terminate the override and allow the fuel to engine to begin to revert to the fueling corresponding to the operators positioning of the accelerator pedal or corresponding device.

The responsive time of the disconnect or interrupt clutch 24 actuator is the time from command from CPU 50 until the clutch 24 moves from disengaged towards full engagement into incipient engagement.

In automated mechanical transmission systems of the type illustrated having a torque converter 20 and separate torque converter lock-up (26) and disconnect (24) clutches, the torque converter lock-up clutch (24) is timed to disengage just prior to the disconnect disengaging, and to reengage just after the disconnect clutch engages to allow the torque converter to slip for a very short period of time to further cushion the shift sequence.

In the case of downshifts, shift quality does not appear to be as important as in upshifts.

Of course, during the shift recovery process the inputs to CPU 50 will constantly be updated as will the required sequence and timing of issuing command signals to the various actuator devices.

For certain off-highway modes of operation, and/or in the lower drive ratios, minimizing torque interrupt time, even at the expense of shift quality, may be desirable. In such situations, the torque converter lock-up clutch 26 is also disengaged during at least all shift transients, the interrupt clutch is timed to reengage as soon as gear ratio engagement occurs, regardless of the value of ES_{DELTA}, and the torque converter and/or increased springiness of the driveline in the lower ratios is utilized to smooth the torque recovery process. In this case, the lock-up clutch will reengage if necessary, shortly after the interrupt clutch engages and the engine is pulled towards input shaft speed.

In view of the above, it may be seen that a control method/system for an automated mechanical transmission system is provided which utilizes a robust torque recovery logic to provide relatively smooth, high quality upshifting.

It is understood that the above description of the preferred embodiment is by way of example only and that various modifications, substitutions and/or rearrangements of the parts are possible without departing from the spirit and the scope of the present invention as hereinafter claimed.

Claims

1. A method for smooth upshifting an automated mechanical transmission system (12) of the type comprising a mechanical transmission (14), a fuel controlled engine (16), a nonpositive coupling (10) drivingly interposed the engine and the transmission, an operator set throttle control device (32), a throttle override device (34) effective to at least decrease the fuel supplied to the engine regardless of the setting of the throttle control device, and a central control unit (50) effective to receive input signals indicative of the status of the transmission system including at least (i) engine speed (36) and to process same in accordance with logic rules to issue command output signals to a plurality of system actuators, including at least (i) a throttle override device actuator, (ii) a nonpositive coupling actuator (38/40) and (iii) a transmission shift actuator, said method including upshifting by a sequence of operations including causing the throttle override device to reduce the fuel supplied to the engine, disengaging the nonpositive coupling, engaging a selected transmission ratio and then performing a torque recovery operation comprising reengaging the nonpositive coupling and fueling the engine in accordance with the setting of the throttle control device; said method characterized by:

    determining a first response time comprising the time required for the nonpositive clutch actuator to respond to a command output signal and move said nonpositive coupling from a disengaged position to a point of initial engagement;

    determining a second response time corresponding to the time required for the throttle override device actuator to respond to a command output signal to begin to allow the engine to be fueled in accordance with the setting of the throttle control device;

    determining a current value of engine deceleration (dES/dt); and

    issuing command signals to said nonpositive coupling actuator and said throttle override device actuator to execute said torque recovery operation in a timed sequence which is a function

of said first and second response times and said current value of engine deceleration.

2. The method of claim 1 further characterized by:
sensing current engine speed ($ES_{CURRENT}$) and determining a target engine speed (E_{SYNC}) related to the rotational speed of a transmission shaft (72), said timed sequence also a function of the difference (ES_{DELTA}) between said current and target engine speeds.

3. The control method of claims 1 or 2 wherein said nonpositive coupling includes a friction clutch drivingly interposed said engine and said transmission.

4. The control method of claims 1 or 2 wherein said nonpositive coupling comprises a torque converter (20) and a friction torque converter disconnect clutch (24).

5. The method of claims 1 or 2 wherein said transmission system includes a power synchronizer assembly (30).

6. The method of claim 3 wherein said transmission system includes a power synchronizer assembly (30).

7. The method of claim 4 wherein said transmission system includes a power synchronizer assembly (30).

8. The method of claims 1 or 2 wherein said throttle override device is a throttle dip device effective when actuated to cause the engine to be fueled at a relative low level regardless of the setting of the throttle control device.

9. The method of claim 4 wherein said throttle override device is a throttle dip device effective when actuated to cause the engine to be fueled at a relative low level regardless of the setting of the throttle control device.

10. The method of claims 1 or 2 wherein said first and second response times are predetermined constant values.

11. The method of claim 3 wherein said first and second response times are predetermined constant values.

12. The method of claim 4 wherein said first and second response times are predetermined constant values.

13. The method of claim 5 wherein said first and sec-

ond response times are predetermined constant values.

14. The method of claim 8 wherein said first and second response times are predetermined constant values.

15. A method for smooth upshifting an automated mechanical transmission system (12) of the type comprising a mechanical transmission (14), a fuel controlled engine (16), a nonpositive coupling (10) including a selectively engagable and disengagable friction clutch drivingly interposed the engine and the transmission, an operator set throttle control device (32), a throttle override device (34) effective to at least decrease the fuel supplied to the engine regardless of the setting of the throttle control device, and a central control unit (50) effective to receive input signals indicative of the status of the transmission system including at least (i) engine speed (ES) (36), (ii) transmission input shaft speed (IS) and (iii) transmission output shaft speed (OS) and to process same in accordance with logic rules to issue command output signals to a plurality of system actuators, including at least (i) a throttle override device actuator, (ii) a nonpositive coupling actuator (30/40) and (iii) a transmission shift actuator, said method including upshifting by a sequence of operations including causing the throttle override device to reduce the fuel supplied to the engine, causing the nonpositive coupling actuator to disengage the nonpositive coupling, causing the transmission shift actuator to engage a selected transmission ratio and then performing a torque recovery operation comprising causing the nonpositive coupling actuator to reengage the nonpositive coupling and causing the throttle override device to allow fueling the engine in accordance with the setting of the throttle control device; said method characterized by:
determining a first response time comprising the time required for the nonpositive clutch actuator to respond to a command output signal and to move said nonpositive coupling friction clutch from a disengaged position to a point of initial engagement;
determining a second response time corresponding to the time required for the throttle override device actuator to respond to a command output signal to begin to allow the engine to be fueled in accordance with the setting of the throttle control device;
determining a current value of engine speed ($ES_{CURRENT}$), engine deceleration (dES/dt); and output shaft speed (OS);
determining as a function of current output shaft speed (OS) and engaged gear ratio, a target

engine speed (ES_{SYNC}); and

issuing command signals to said nonpositive coupling actuator and said throttle override device actuator to execute said torque recovery operation in a timed sequence which is a function of said first and second response times, said current value of engine deceleration and the difference between the current engine speed and the target engine speed.

16. The method of claim 15 wherein said timed sequence is determined to cause said friction coupling to initially engage and said throttle override device to allow fueling of said engine in accordance with said throttle control device at about the same instant in time when the engine speed ES will equal the target engine speed (ES_{SYNC}) at current engine deceleration (dES/dt).

17. The method of claims 15 or 16 wherein said transmission system includes a power synchronizer assembly (30).

18. The method of claims 15 or 16 wherein said throttle override device is a throttle dip device effective when actuated to cause the engine to be fueled at a relative low level regardless of the setting of the throttle control device.

19. The method of claim 17 wherein said throttle override device is a throttle dip device effective when actuated to cause the engine to be fueled at a relative low level regardless of the setting of the throttle control device.

20. The method of claims 15 or 16 wherein said first and second response times are predetermined constant values.

21. A control system for smooth upshifting an automated mechanical transmission system (12) of the type comprising a mechanical transmission (14), a fuel controlled engine (16), a nonpositive coupling (10) drivingly interposed the engine and the transmission, an operator set throttle control device (32), a throttle override device (34) effective to at least decrease the fuel supplied to the engine regardless of the setting of the throttle control device, and a central control unit (50) effective to receive input signals indicative of the status of the transmission system including at least (i) engine speed (36) and to process same in accordance with logic rules to issue command output signals to a plurality of system actuators, including at least (i) a throttle override device actuator, (ii) a nonpositive coupling actuator (38/40) and (iii) a transmission shift actuator, said control system including logic rules for upshifting by a sequence of operations including causing the throttle override device to reduce the fuel supplied to the engine, disengaging the nonpositive coupling, engaging a selected transmission ratio and then performing a torque recovery operation comprising reengaging the nonpositive coupling and fueling the engine in accordance with the setting of the throttle control device; said control system characterized by said logic rules including rules:

for determining a first response time comprising the time required for the nonpositive clutch actuator to respond to a command output signal and move said nonpositive coupling from a disengaged position to a point of initial engagement;

for determining a second response time corresponding to the time required for the throttle override device actuator to respond to a command output signal to begin to allow the engine to be fueled in accordance with the setting of the throttle control device;

for determining a current value of engine deceleration (dES/dt); and

for issuing command signals to said nonpositive coupling actuator and said throttle override device actuator to execute said torque recovery operation in a timed sequence which is a function of said first and second response times and said current value of engine deceleration.

22. The control system of claim 21 further characterized by said logic rules further including rules:

for sensing current engine speed ($ES_{CURRENT}$) and determining a target engine speed (E_{SYNC}) related to the rotational speed of a transmission shaft (72), said timed sequence also a function of the difference (ES_{DELTA}) between said current and target engine speeds.

23. The control system of claims 21 or 22 wherein said nonpositive coupling includes a friction clutch drivingly interposed said engine and said transmission.

24. The control system of claims 21 or 22 wherein said nonpositive coupling comprises a torque converter (20) and a friction torque converter disconnect clutch (24).

25. The control system of claims 21 or 22 wherein said transmission system includes a power synchronizer assembly (30).

26. The control system of claim 23 wherein said transmission system includes a power synchronizer assembly (30).

27. The control system of claims 21 or 22 wherein said throttle override device is a throttle dip de-

vice effective when actuated to cause the engine to be fueled at a relative low level regardless of the setting of the throttle control device.

28. The control system of claims 21 or 22 wherein said first and second response times are predetermined constant values.

29. The control system of claim 23 wherein said first and second response times are predetermined constant values.

30. The control system of claim 24 wherein said first and second response times are predetermined constant values.

31. A control system for smooth upshifting an automated mechanical transmission system (12) of the type comprising a mechanical transmission (14), a fuel controlled engine (16), a nonpositive coupling (10) including a selectively engagable and disengagable friction clutch drivingly interposed the engine and the transmission, an operator set throttle control device (32), a throttle override device (34) effective to at least decrease the fuel supplied to the engine regardless of the setting of the throttle control device, and a central control unit (50) effective to receive input signals indicative of the status of the transmission system including at least (i) engine speed (ES) (36), (ii) transmission input shaft speed (IS) and (iii) transmission output shaft speed (OS) and to process same in accordance with logic rules to issue command output signals to a plurality of system actuators, including at least (i) a throttle override device actuator, (ii) a nonpositive coupling actuator (30/40) and (iii) a transmission shift actuator, said control system including logic rules for upshifting by a sequence of operations including causing the throttle override device to reduce the fuel supplied to the engine, causing the nonpositive coupling actuator to disengage the nonpositive coupling, causing the transmission shift actuator to engage a selected transmission ratio and then performing a torque recovery operation comprising causing the nonpositive coupling actuator to reengage the nonpositive coupling and causing the throttle override device to allow fueling the engine in accordance with the setting of the throttle control device; said control system characterized by said logic rules including rules:

for determining a first response time comprising the time required for the nonpositive clutch actuator to respond to a command output signal and to move said nonpositive coupling friction clutch from a disengaged position to a point of initial engagement;

for determining a second response time

corresponding to the time required for the throttle override device actuator to respond to a command output signal to begin to allow the engine to be fueled in accordance with the setting of the throttle control device;

for determining a current value of engine speed ($ES_{CURRENT}$), engine deceleration (dES/dt); and output shaft speed (OS);

for determining as a function of current output shaft speed (OS) and engaged gear ratio, a target engine speed (ES_{SYNC}); and

for issuing command signals to said nonpositive coupling actuator and said throttle override device actuator to execute said torque recovery operation in a timed sequence which is a function of said first and second response times, said current value of engine deceleration and the difference between the current engine speed and the target engine speed.

32. The control system of claim 31 wherein said timed sequence is determined to cause said friction coupling to initially engage and said throttle override device to allow fueling of said engine in accordance with said throttle control device at about the same instant in time when the engine speed ES will equal the target engine speed (ES_{SYNC}) at current engine deceleration (dES/dt).

33. The control system of claims 31 or 32 wherein said transmission system includes a power synchronizer assembly (30).

34. The control system of claims 31 or 33 wherein said throttle override device is a throttle dip device effective when actuated to cause the engine to be fueled at a relative low level regardless of the setting of the throttle control device.

35. The control system of claims 31 or 32 wherein said first and second response times are predetermined constant values.

36. The control system of claim 35 wherein said rules for determining said first and second response times comprise rules for accessing said predetermined constant values.
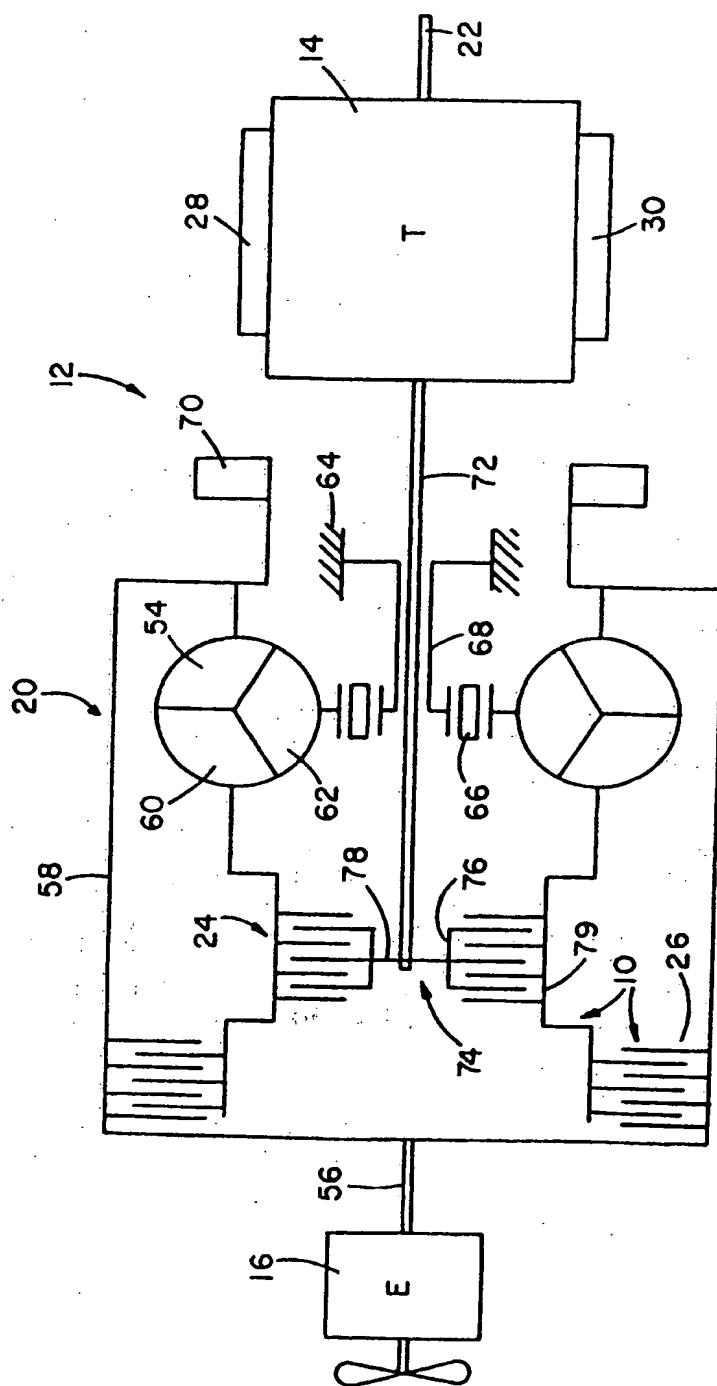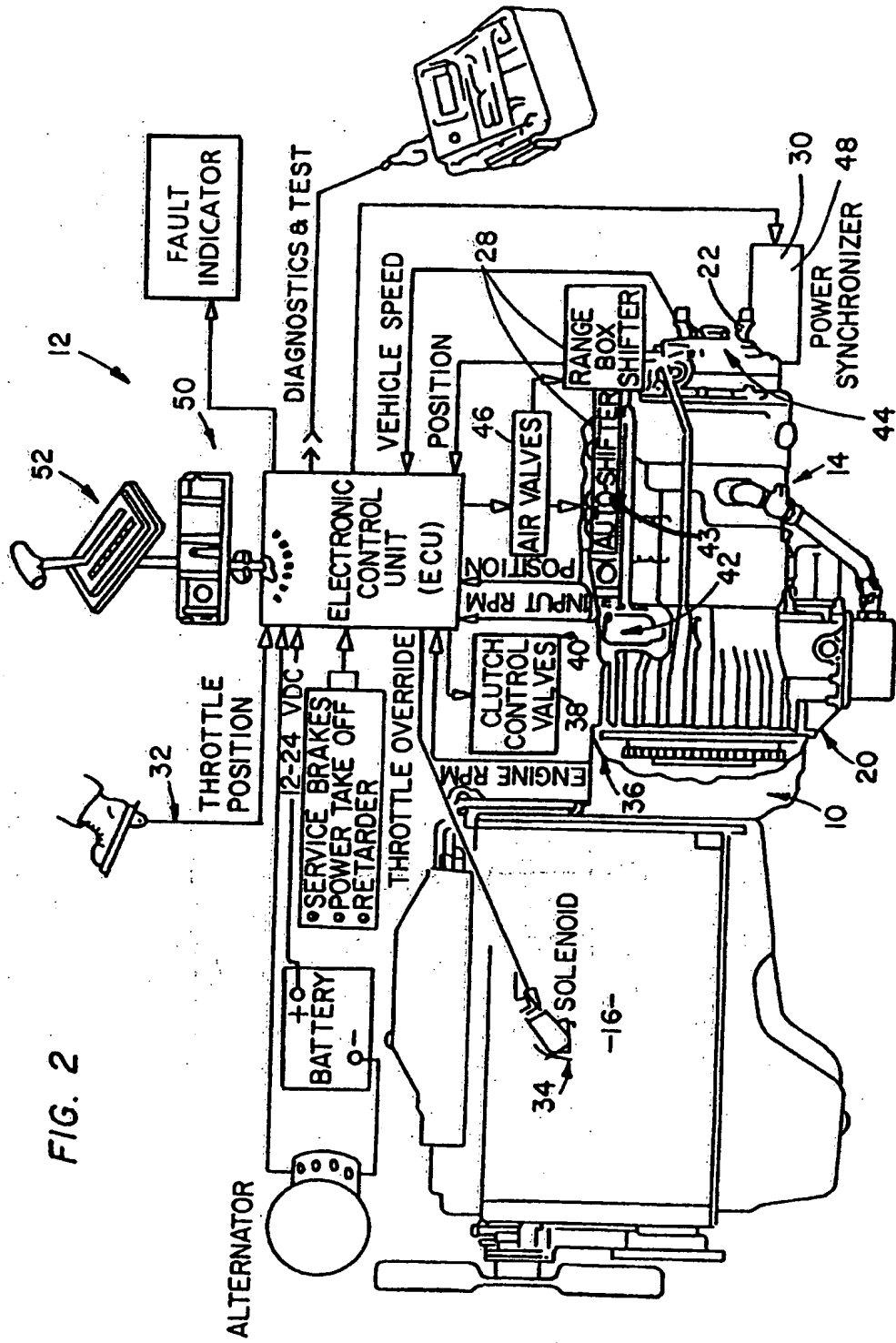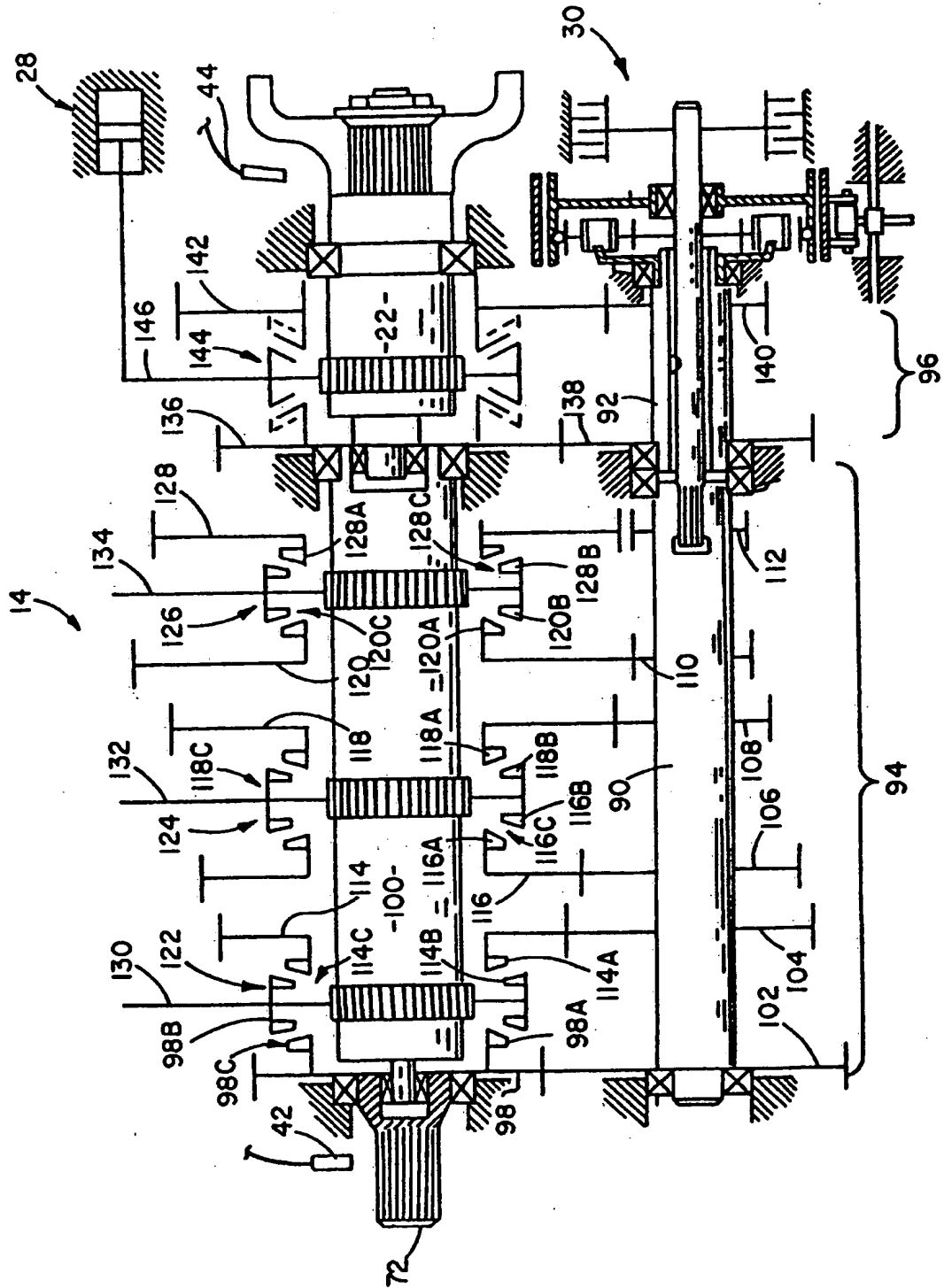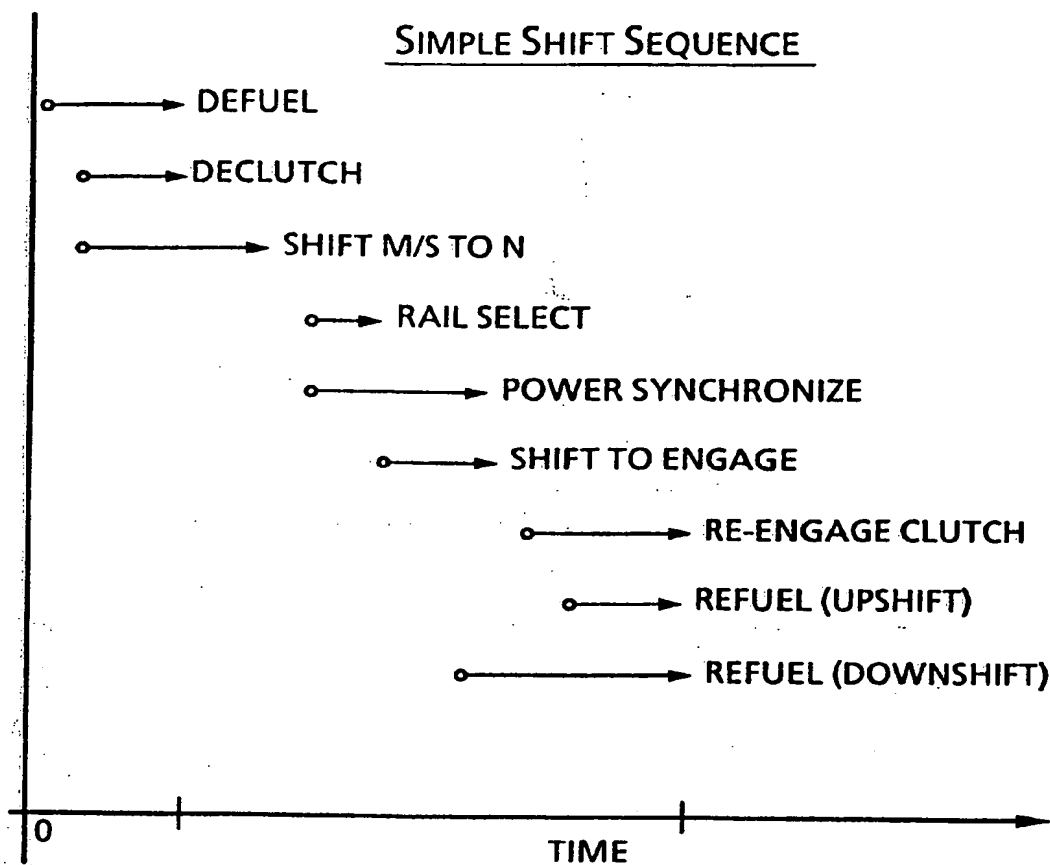
FIG. 1

FIG. 2

FIG. 3

SIMPLE SHIFT SEQUENCE

- → DEFUEL
- → DECLUTCH
- → SHIFT M/S TO N
  - → RAIL SELECT
  - → POWER SYNCHRONIZE
  - → SHIFT TO ENGAGE
    - → RE-ENGAGE CLUTCH
    - → REFUEL (UPSHIFT)
    - → REFUEL (DOWNSHIFT)

0   TIME

FIG. 4

L   2/6   4/8

N

R   1/5   3/7

FIG. 5